Titanium-zirconium narrow-diameter versus titanium regular-diameter implants for anterior and premolar single crowns: 3-year results of a randomized controlled clinical study.

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Abstract: AIM To test whether titanium-zirconium (Ti-Zr) 3.3 mm diameter implants perform differently from titanium (Ti) 4.1 mm diameter implants with respect to marginal bone level (MBL) and clinical parameters. MATERIAL AND METHODS Forty patients in need of a single-implant crown in the anterior or premolar regions were enrolled in two centres. Following random allocation, either a Ti-Zr or a Ti implant was inserted. Porcelain-fused-to-metal crowns were inserted 6 months after implantation. Implant survival, change in MBL, clinical parameters, change in mid-facial mucosa and papilla levels, and the occurrence of biological and technical complications were assessed at the 3-year follow-up. RESULTS At 3 years, 32 of the 40 included patients were examined (15 Ti, 17 Ti-Zr). There were no implant failures. From the implant placement to 3 years, the median change in mean MBL amounted to 0.21 mm (mean: -0.31) in the Ti group and 0.10 mm (mean: -0.40) in the Ti-Zr group. There were no significant differences between the groups with respect to the change in MBL, the change in mucosa levels, and the occurrence of complications. CONCLUSIONS Ti-Zr implants with 3.3 mm diameter used for the support of single crowns in the anterior and the premolar regions did not differ from Ti implants with 4.1 mm diameter regarding the clinical performance over a 3-year period.

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Titanium-zirconium narrow-diameter versus titanium regular-diameter implants for anterior and premolar single crowns: 3-year results of a randomized controlled clinical study

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Abstract

Aim: To test whether titanium-zirconium (Ti-Zr) 3.3 mm diameter implants perform differently from titanium (Ti) 4.1 mm diameter implants with respect to marginal bone level (MBL) and clinical parameters.

Material and Methods: Forty patients in need of a single-implant crown in the anterior or premolar regions were enrolled in two centres. Following random allocation, either a Ti-Zr or a Ti implant was inserted. Porcelain-fused-to-metal crowns were inserted 6 months after implantation. Implant survival, change in MBL, clinical parameters, change in mid-facial mucosa and papilla levels, and the occurrence of biological and technical complications were assessed at the 3-year follow-up.

Results: At 3 years, 32 of the 40 included patients were examined (15 Ti, 17 Ti-Zr). There were no implant failures. From the implant placement to 3 years, the median change in mean MBL amounted to 0.21 mm (mean: -0.31) in the Ti group and 0.10 mm (mean: -0.40) in the Ti-Zr group. There were no significant differences between the groups with respect to the change in MBL, the change in mucosa levels, and the occurrence of complications.

Conclusions: Ti-Zr implants with 3.3 mm diameter used for the support of single crowns in the anterior and the premolar regions did not differ from Ti implants with 4.1 mm diameter regarding the clinical performance over a 3-year period.

Clinical Relevance
Scientific rationale for the study: Narrow-diameter implants were introduced to overcome clinical situations with reduced bone width bucco-orally or a narrow mesio-distal tooth-gap. The strength of narrow-diameter titanium implants however is limited and thus implant fractures may occur. By alloying titanium to other metals like zirconium (titanium-zirconium), the strength of narrow-diameter implants can be improved.

Principal findings: Narrow-diameter (3.3 mm) titanium-zirconium implants did not perform differently from regular-diameter (4.1 mm) titanium implants regarding the change in marginal bone level from the implant placement to the 3-year examination. During this observation period there were no implant failures. Furthermore, there were no significant differences between the groups with respect to clinical parameters and occurrences of adverse events.

Practical implications: The use of titanium-zirconium narrow-diameter implants for the support of single crowns in the anterior and premolar regions leads to successful tissue integration and clinical performance over a 3-year period. Longer observation periods are required to recommend the use of titanium-zirconium implants with narrow diameter for this clinical indication.

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Introduction

Placing dental implants into native bone or in conjunction with bone augmentation procedures is a predictable treatment option to prosthetically restore the edentulous jaw regions (Jung et al., 2012, Benic et al., 2009, Hammerle et al., 2002). Due to the reduced bucco-oral dimension of the edentulous alveolar ridge, the prosthetically driven implant placement is frequently associated with the presence of peri-implant bone dehiscences and fenestrations. In terms of mesio-distal gap dimension, an adequate distance between teeth and implants is required to reduce the amount of subsequent bone resorption and recession of the papillae (Esposito et al., 1993, Tarnow et al., 2000). The challenging clinical situations with limited mesio-distal amount of space or reduced ridge width can be overcome by using narrow-diameter implants (Davarpanah et al., 2000).

A recent systematic review of clinical trials found survival rates of narrow-diameter (3.0 – 3.5 mm) implants ranging from 89% to 100% (Klein et al., 2014). The meta-analysis of the data showed no statistically significant differences in implant survival between implants with 3.3 – 3.5 mm diameter and those with conventional diameter (3.75 – 4.1 mm). It was, however, found that there is insufficient evidence on the success rates for implants with narrow diameter (Klein et al., 2014). It is known that fatigue fractures of narrow-diameter implants may occur after a long period of loading (Zinsli et al., 2004). The risk of biomechanical problems and the limited knowledge of their clinical behaviour should, therefore, be taken into account when using implants with narrow diameter (Bornstein et al. 2014).

The strength of titanium (Ti) implants can be increased, by alloying Ti with other metals, such as zirconium (Kobayashi et al., 1995, Grandin et al., 2012). A titanium-zirconium (Ti-Zr) alloy, made of 83-87% Ti and 13-17% Zr, was developed and introduced for the fabrication of narrow-diameter implants (Berner et al., 2009). Preclinical investigations revealed that Ti-Zr implants perform similar to Ti implants with respect to osseointegration

(Thoma et al., 2011, Gottlow et al., 2012, Saulacic et al., 2012, Anchieta et al., 2013, Wen et al., 2013).

The clinical performance of narrow-diameter Ti-Zr implants was investigated in several previous clinical trials (Chiapasco et al., 2012, Benic et al., 2013, Anchieta et al., 2013) In those studies high survival and success rates for Ti-Zr narrow-diameter implants were observed after short periods of observation. A recent randomized controlled trial compared narrow-diameter Ti-Zr and Ti implants for the support of mandibular overdentures (Al-Nawas et al., 2012). In this study no differences were found between Ti-Zr and Ti implants with respect to the change in marginal bone level (MBL), the implant survival and the success rate after 3 years of observation (Quirynen et al., 2014). However, there is insufficient comparative evidence available on the clinical performance of narrow-diameter Ti-Zr implants for the support of fixed partial dentures in the load bearing jaw regions.

Therefore, the primary aim of the present randomized controlled clinical trial was to test whether Ti-Zr 3.3 mm diameter implants, placed to support single crowns in the anterior and the premolar regions, render different results from Ti 4.1 mm diameter implants with respect to the change in MBL over a 3-year period. The null hypothesis was that the treatment modalities do not differ with respect to the change in MBL from the implant placement to the 3-year follow-up. In addition, the implant survival, the soft tissue parameters and the complication rate were assessed.

Material and Methods

This article is reported according to the CONSORT guidelines for reporting parallel group randomized trials (Moher et al., 2010).

Study design

This study was designed as a prospective randomized controlled clinical trial with two parallel study groups and a duration period of 5 years. The study was conducted at two centres (Clinic of Fixed and Removable Prosthodontics and Dental Material Science, Center of Dental Medicine, University of Zurich, Zurich, Switzerland and Department of Restorative Dentistry and Biomaterials Sciences, Harvard School of Dental Medicine, Boston, MA, USA). The clinical protocol was approved by the respective local ethical committees.

Study population

Each centre recruited 20 subjects for a total of 40 patients in need of an implant-supported crown for the restoration of a single-tooth gap in the anterior or the premolar regions of upper or lower jaw.

The subjects had to fulfil the following inclusion criteria:

- ≥18 years of age
- No medical history in which any elective oral surgical intervention would be contraindicated
- No heavy smoking (>20 cigarettes per day)
- No active periodontal disease
- Full-mouth plaque score (FMPS) and full-mouth bleeding score (FMBS) <25%
- Need of an implant-supported crown at a single-tooth gap in regions 11–15, 21–25, 31–35, 41–45 (FDI)
- Presence of mesial and distal natural teeth
- Adequate quantity of native bone to allow the placement of an implant with 4.1 mm diameter and 8 mm length with at least 2 mm of distance to the mandibular alveolar canal.

The pre-operative assessment of the apico-coronal amount of bone available was performed by means of a panoramic radiograph.

Need of primary bone augmentation and absence of primary stability at the time of implant placement were considered exclusion criteria.

A signed informed consent was obtained from all the patients prior to any study treatments.

Randomization and allocation concealment

All patients were randomly allocated to one of the two treatment modalities according to a computer-generated randomization list. Two separated lists were created for the two study centers. To generate the allocation sequence, a permuted-block randomization with block sizes of 4 and allocation ratio of 1:1 was applied. In the case that two or more sites per patient were available, fulfilling the inclusion criteria, one gap was selected by throwing a die. Allocation to the study groups was concealed by using sealed envelopes until the time of surgical procedure that required the preparation of the implant bed.

Treatment procedures

The time sequence of interventions and assessments is represented in Fig. 1. All investigators participating in the study were experienced in implant placement and bone augmentation procedures. Before the study initiation, all participating clinicians attended a training session to standardize the patient selection and the therapeutic procedure and to calibrate the assessment techniques.

The placement of implants was performed either as type 2, type 3 or type 4 procedure (Hammerle et al., 2004). Prior to implant insertion, the patients received antibiotics (2 x 750 mg amoxicillin) and non-steroidal analgesics/antiphlogistics. The surgery was performed under local anaesthesia. A crestal incision and, if needed, a vertical release incision were performed and the mucoperiostal flaps were elevated. In the case that the amount of bone was found to be insufficient for implant placement, the patient was considered ineligible for the study and an alternative treatment following good clinical standards was offered. The implant bed was prepared according to the manufacturer's instruction for the placement of Straumann Bone Level implants (Institut Straumann AG, Basel, Switzerland).

One of the following randomly assigned implants was inserted:

- Test group: a Ti-Zr 3.3 mm diameter implant (Straumann® Bone Level, Roxolid®, SLActive®, Institut Straumann AG)
- Control group: a Ti 4.1 mm diameter implant (Straumann® Bone Level, Ti, SLActive®, Institut Straumann AG).

The implant stability was assessed by mechanical testing with a hand instrument (e.g. periodontal probe). In the event that the implant lacked primary stability (visible mobility on mechanical testing), the subject was excluded from the study and an alternative treatment was offered following good clinical standards. Peri-implant bone dehiscences, fenestrations, infrabony defects measuring >0.5 mm of width, and thin bone plates were grafted with particulated deproteinized bovine bone mineral (BioOss® Spongiosa Granules; Geistlich Pharma AG, Wolhusen, Switzerland) and covered with a native collagen membrane (BioGide®; Geistlich Pharma AG). If needed, the membrane was fixed by using resorbable pins (Inion GTR™, Inion Ltd., Tampere, Finland). A cover screw was placed and the mucosal flaps were sutured using ePTFE non-resorbable monofilament sutures (Gore-Tex®, Gore, Flagstaff, AZ, USA). All the implants healed in a submerged position. The patients were instructed to rinse the oral cavity twice daily with 0.2% chlorhexidine-digluconate and analgesics (mefenamic acid 500 mg) were prescribed for the first 3 days according to the individual needs. In cases of guided bone regeneration, the patients received antibiotics for 5 days (3 x 750 mg/day amoxicillin). The sutures were removed 7 days after implant placement. Post-surgical examinations including supra-gingival cleaning were performed 2 and 6 weeks after implant insertion.

Three months after the implant placement, the re-entry surgery was performed under local anaesthesia. After crestal incision and flap elevation, cover screws were replaced by healing abutments. When necessary, provisional crowns were inserted to condition the peri-implant soft tissue. The final porcelain-fused-to-metal single screw- or cement-retained crowns were placed 6 months after the implantation. All the patients were recalled for the follow-up assessment 1 and 3 years after the implant placement (Fig. 2).

Outcome variables

Implant survival

Implant survival was assessed at the 3-year follow-up. The implant survival was defined as the implant being in place and stable. The stability of the implant-supported reconstruction and, if necessary, of the implant were assessed by mechanical testing with a hand instrument.

Marginal bone level

Periapical radiographs were taken immediately after implant insertion, at 6 months, at 1 year and at 3 years. Standardized radiographs were taken by using individualized X-ray film holder devices. The individualization of the film holder was performed with a bite-registration material (R-SI-Line Metal-Bite, R-dental GmbH, Hamburg, Germany). The film was positioned parallel to the implant axis and the X-ray beam directed perpendicular to the implant. The radiographs were digitized as jpeg files and imported in the ImageJ 1.43 open-source software (National Institute of Health, Bethesda, MD, USA). A calibrated investigator, who was unaware of the treatment strategy and the aim of the study, evaluated all the radiographic images.

The marginal bone level (MBL) was assessed on the mesial and on the distal aspect of each implant by measuring the distance between the implant shoulder and first bone-to-implant contact. The known distance between implant threads was used for the calibration of the images. Mesial and distal MBL values were averaged to one value per implant. The changes in MBL from implant placement to 6, 12 and 36 months examinations were calculated. A negative change of MBL denoted a loss of marginal bone.

Clinical parameters

At the 1- and 3-year follow-up examinations, the following variables were assessed:

- Full-mouth plaque score (FMPS) at six sites per tooth/implant (O'Leary et al., 1972)
- Full-mouth bleeding on probing score (FMBS) at six sites per tooth/implant (Ainamo and Bay, 1975)
- Plaque control record (PCR) at six sites per study implant (O'Leary et al., 1972)
- Bleeding on probing score (BOP) at six sites per study implant (Ainamo and Bay, 1975)
- Probing pocket depth (PPD) at six sites per study implant
- Width of the keratinized mucosa (KM) at the mid-buccal aspect of the study implant

Mid-facial mucosa and papilla levels

After the insertion of the final crown (6 months after implantation), at the 1- and 3-year examinations, the levels of the mid-facial mucosa and of the inter-proximal papillae were assessed. The tangent to the incisal edge/buccal cusp of the implant-supported crown was used as the reference line. The measurements were performed with a periodontal probe and the values approximated to the nearest 0.5 mm.

The changes in mucosa levels from 6 months to 1 and 3 years were calculated. A negative value denoted a reduction in soft tissue level.

Adverse events and complications

The occurrence of adverse events (AE) and biological and technical complications was recorded at each study visit. The following biological complications were assessed: implant mobility, persistent subjective complaints, continuous peri-implant radiolucency, peri-implant infection with suppuration (Buser et al., 1990). Peri-implantitis was defined as bone loss > 2 mm in combination with a positive BOP recording (Sanz et al., 2012). The list of the technical complications included: implant fracture, abutment fracture, fracture of the veneering ceramic, loosening of the abutment screw, fracture of the abutment screw. If

needed, appropriate treatment was performed and the patient was monitored until the AE or complication was resolved.

Statistical analysis

The statistical analysis was performed with SPSS Statistics 20.0 (SPSS Inc., Chicago, IL, USA) and Stat X act 11.0 (Cytel, Cambridge, MA, USA).

The primary parameter was the change of MBL from the implant placement to the 3-year examination. The sample size calculation was based on two independent groups, a normal distribution and the two-sample t-test. To detect a difference of 0.5 mm with a standard deviation (SD) of 0.5 mm (power: 80%, significance level: 0.05), 17 patients per group (total of 34 patients) were required. To compensate for possible drop-outs, the sample size was increased to 20 patients per group (total of 40 patients).

For the statistical analysis the six values around each implant for PCR, BOP and PPD and the two values for MBL and papilla level at the mesial and distal aspect were averaged to one value each. For MBL and papilla level, the mesial, the distal and the mean values were analyzed separately. For discrete variables, the absolute and the relative frequencies were calculated. For continuous parameters, the data distributions were represented with boxplots and the data were reported by using means, standard deviations (SD), ranges, medians, and interquartile ranges (IQR). The non-parametric Mann–Whitney test was applied to detect differences between the groups because of non-normality of the data. To analyse the centre effect on the primary endpoint, the non-parametric Hodges-Lehmann estimate together with the non-parametric 95% confidence intervals (CI) were used. For implant survival, the 95% CI for the true survival was computed. Results of tests with p-values ≤ 0.05 were considered statistically significant. No correction for multiple testing was performed for the analyses of the secondary endpoints.

Results

Patients

A total number of 40 patients were included in this study from January 2010 to December 2010. Of these, 20 were randomized to the Ti group and 20 to the Ti-Zr group. There were no significant differences between the treatment groups with respect to the following parameters: patient gender, patient age, smoking, implant location and time point of implant placement after tooth extraction ($p > 0.05$) (Table S1). At 3 years, 32 out of the 40 included patients attended the follow-up examination, rendering a recall rate of 80%. Two subjects had moved and were classified as lost to follow-up between 6 and 12 months. Between 1 and 3 years, 6 patients had moved or passed away and could not be recruited for the follow-up examination.

Implant survival

At the 1-year follow-up, 18 Ti and 20 Ti-Zr implants were evaluated. At 3 years, 15 out of 20 Ti implants (75%) and 17 out of 20 Ti-Zr implants (85%) were examined. During the entire study observation period, no implant failures were recorded, yielding a 3-year implant survival rate of 100% for both the Ti (95% CI: 78%; 100%) and the Ti-Zr groups (95% CI: 80%; 100%).

Marginal bone level

From the implant placement to the 3-year follow-up, the median change of mean MBL amounted to 0.21 mm (mean ± SD: -0.31 ± 0.59 mm in the Ti group and 0.10 mm (mean ± SD: -0.40 ± 0.93 mm) in the Ti-Zr group with no significant difference between the groups ($p = 0.720$) (Table 1, Fig. 3).

The centre effect on the change in MBL from the implant placement to the 3-year examination was not statistically significant ($p = 0.058$). When analysing the data for each centre separately, the differences between the treatment groups were not statistically significant (Boston: 95% CI: -0.09, 1.04 mm; Zurich: 95% CI: -0.51, 0.24 mm).

From the 1-year to the 3-year examination, the median change in mean MBL measured -0.01 mm (mean ± SD: 0.14 ± 0.59 mm) for the Ti implants and -0.04 mm (mean ± SD: -0.05 ± 0.41 mm) for the Ti-Zr implants. The difference between the groups was not statistically significant ($p = 0.692$) (Table 1, Fig. 3).

When analysing the changes in the mesial and in the distal MBL separately, there were no significant differences between the Ti and the Ti-Zr groups for the period from implant placement to the 3-year examination (mesial: $p = 0.880$; distal: $p = 0.637$ distal) and the period from 1 to 3 years (mesial: $p = 0.417$; distal: $p = 0.777$).

The frequency distributions of the changes in MBL from the implant placement to the 1-year examination were described in a previous publication (Benic et al., 2013). The corresponding results from implant placement to the 3-year follow-up are represented in Figure 4. One year after implant placement, there were two Ti-Zr implants with >2 mm of bone loss at the mesial aspect and one Ti implant with >2 mm of bone loss at the distal aspect. One of the two Ti-Zr implants could not be examined at 3 years because the patient was lost to follow-up. At the 3-year examination, two Ti-Zr implants and no Ti implants were observed with >2 mm of bone loss.

Clinical parameters

The results of FMPS, PCR, BOP and KM are presented in Table 2. At 3 years, there were no statistically significant differences in FMPS, PCR, BOP and KM between the groups ($p > 0.05$). The median FMBS amounted to 12 % (mean ± SD: 15.7 ± 11.6 %) for Ti implants and 4 % (mean ± SD: 6.9 ± 7.3 %) for Ti-Zr implants. The difference in FMBS between the groups reached statistical significance ($p = 0.028$).

Mid-facial mucosa and papilla levels

The results of the changes in facial mucosa and papilla levels are presented in Table 3. From the 6-month to the 1-year examination, the median change in mid-facial mucosa level measured 0 mm (mean ± SD: 0.2 ± 0.6 mm) for the Ti implants and 0 mm (0.0 ± 0.8 mm) for the Ti-Zr implants. The difference between the groups did not reach statistical significance ($p = 0.480$). From the crown insertion (6 months after implantation) to the 3-year follow-up, the median change of mid-facial mucosa level amounted to 0.5 mm (mean ± SD: -0.3 ± 1.1 mm) in the Ti group and -0.5 mm (mean ± SD: -0.3 ± 0.9 mm) in the Ti-Zr group with no signifi

cant difference between the groups ($p = 0.281$) (Table 3).

In terms of change in mesial and distal papilla levels, there were no significant differences between the groups ($p > 0.05$) (Table 3).

Adverse events and complications

Postoperative complications were described in a previous publication (Benic et al., 2013).

From 6 months to 3 years, there were no cases of implant mobility, persistent subjective complaints, continuous peri-implant radiolucency, or peri-implant infection with suppuration. At 3 years, one Ti-Zr implant was diagnosed with peri-implantitis (1/17 = 5.9%) according to the specific definition (Sanz et al., 2012). Another Ti-Zr implant was affected by peri-implantitis at the 1-year follow-up. This patient could not be recruited for the 3-year examination.

At the 3-year follow-up, it bled on probing at totally 18 implants. Therefore, according to the specific definition (Sanz et al., 2012) peri-implant mucositis was diagnosed at 10 Ti implants and at 8 Ti-Zr implants.

At the 3-year follow-up, two technical complications were recorded in the Ti-Zr group (2/17 = 11.8%): one polishable fracture of the veneering ceramic and one loosening of the abutment screw. At 3 years, one polishable chipping of the veneering ceramic was observed in the Ti group (1/15 = 6.7%).

Discussion

The results of the present randomized controlled clinical study suggest that Ti-Zr 3.3 mm diameter and Ti 4.1 mm diameter two-piece implants do not differ with respect to the change in marginal bone level from the implant placement to the 3-year examination. There were no implant failures during the 3-year observation period. Furthermore, there were no differences between the Ti-Zr narrow-diameter and the Ti regular-diameter implants regarding the soft tissue parameters and the changes of the peri-implant mucosal level.

These results are in accordance with the data reported in previous clinical studies investigating Ti-Zr 3.3 mm diameter implants. In a recent randomized controlled, double-blind, split-mouth trial, 3.3 mm-diameter two-piece Ti and Ti-Zr implants were compared (Quirynen et al., 2014). All the patients received one Ti and one Ti-Zr implant in the interforaminal region of the edentulous mandible. Implants were loaded after 6–8 weeks with removable locator-retained over-dentures. Of the 91 treated patients, 75 completed the 3-year follow-up. One Ti-Zr and two Ti implants were lost, yielding a 3-year survival rate of 98.7% for Ti-Zr implants and 97.3% for Ti implants. With respect to the implant survival and the change in MBL, there were no statistically significant differences between the groups. The change of mean MBL between implant placement and 3 years reached -0.78 mm for Ti-Zr implants and -0.60 mm for Ti implants. In a pilot clinical study, 22 patients received Ti-Zr one-piece 3.3 mm diameter implants for the support of fixed reconstructions in the anterior and the premolar regions (Barter et al., 2012). The Ti-Zr narrow-diameter implants were splinted either to regular- or to wide-diameter implants. At 2 years, the survival rate of the Ti-

Zr implants reached 95.2% and the mean change of MBL was -0.33 mm. Another clinical study assessed the use of narrow-diameter one-piece Ti and Ti-Zr implants placed in the posterior region of the jaw to support single crowns (Tolentino et al., 2014). In this randomized controlled trial, 21 patients received a 3.3 mm-diameter Ti-Zr implant and 21 subjects were treated with a 3.3 mm-diameter Ti implant. During the first 6 weeks after implant placement, one implant was lost in each group. At the 1-year examination, the survival and the success rates amounted to 95.2 % for both groups (Tolentino et al., 2014).

In the present study, no implant fractures occurred. At 3 years, two technical complications were observed in the test group, corresponding to a technical complication rate of 11.8%. In a recent systematic review, the cumulative 5-year rate for technical complication rate for single implant crowns reached 8.8% (Jung et al., 2012). Abutment- and screw-loosening, loss of retention and fracture of the veneering material were the most frequent technical complications (Jung et al., 2012). These data are in accordance with the findings of the present clinical trial.

The main limitation of the present study is the fact that the treatment groups differed regarding the implant material and the implant diameter. Therefore, no conclusions can be drawn on implant diameter or implant material separately. Moreover, the difference in two variables represents a potential confounder since both parameters may be associated with the study outcome. In this context it has to be emphasized that several preclinical and clinical trials found no differences between Ti-Zr and Ti implants with respect to osseointegration and change in the marginal bone level (Thoma et al., 2011, Al-Nawas et al., 2012, Quirynen et al., 2014, Gottlow et al., 2012, Saulacic et al., 2012, Anchieta et al., 2013, Wen et al., 2013). As far as the clinical relevance is concerned, the main question is whether narrow-diameter implants made of Ti-Zr represent a valid alternative to the Ti regular-diameter implants, which are considered the gold standard for single tooth gaps in the anterior and the premolar regions. The present study aimed to answer this question. Another limitation of the

present study is given by the fact that implants with and without GBR of peri-implant defects were included. This variable represents a potential confounder of the primary outcome. Currently, there is a high level of evidence that implants placed simultaneously with GBR do not differ from the implants placed into pristine bone with respect to the interproximal marginal bone levels (Benic and Hammerle, 2014, Benic et al., 2009, Jung et al., 2013, Mayfield et al., 1998, Zumstein et al., 2012). Moreover, in the current trial the treatment groups did not differ regarding the distribution of cases with GBR.

The results of the present study are promising, since the use of narrow-diameter implants has the potential to preserve the peri-implant tissue and, consequently, to reduce the need for bone grafting procedures (Papadimitriou et al., 2014, Caneva et al., 2010). However, more clinical long-term investigations are needed reporting survival and success rates of narrow-diameter implants. When using implants with narrow diameter, it is therefore, recommended to take into account the potential risk of biomechanical complications.

Conclusions

Within the limitation of the present randomized controlled trial it can be concluded that the Ti-Zr 3.3 mm diameter implants do not differ from the Ti 4.1 mm diameter implants with respect to the change in MBL from the implant placement to the 3-year examination. From 1 to 3 years, the implants under investigation exhibited stable MBL. During the 3-year observation period there were no implant failures and no device-related serious adverse events. Moreover, no differences regarding the soft tissue parameters and the changes in the mucosa levels were found between the groups.

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Table Legends

Table 1. (a) Results of the marginal bone level at the implant placement, at 6 months, at 1 year and at 3 years. (b) Results of the change in marginal bone level from the implant placement to 1 year, from implant placement to 3 years and from 1 year to 3 years (negative values represent bone loss).

Table 2. Results of the clinical parameters at 3 years.

Table 3. Results of (a) change in the mesial papilla level, (b) change in the distal papilla level and (c) change in the mid-facial mucosa level from 6 months to 3 years (negative values represent mucosal recession).

Figure Legends

Figure 1. Time sequence of interventions and examinations.

Figure 2. (a) Intra-operative situation of site 13 after the placement of a titanium-zirconium implant with 3.3 mm diameter. (b) Occlusal view after the soft tissue healing. (c) Occlusal view and (d) facial view after the insertion of the definitive porcelain-fused-to-metal crown. (e) Occlusal view, (f) facial view and (g) periapical radiograph at the 3-year follow-up.

Figure 3. Box plots representing the mean marginal bone levels (in mm) relative to the

implant shoulder at the implant placement, at 6 months, at 1 year and at 3 years (a) in the titanium 4.1 mm diameter (Ti 4.1) and (b) in the titanium-zirconium 3.3 mm diameter (Ti-Zr 3.3) groups. Box plots depicting the change of mean marginal bone level (in mm) from the implant placement to 3 years and from 1 year to 3 years (c) in the Ti 4.1 and (d) in the Ti-Zr 3.3 groups. ° and * in the figure represent the outliers.

Figure 4. Frequency distributions of the changes in (a) mesial, (b) distal and (c) mean marginal bone level (in mm) from the implant placement to the 3-year examination.

			Ti 4.1					Ti-Zr 3.3		
			n	Mean ± SD	Median	IQR	Range	n	Mean ± SD	Median
(a) Marginal bone level (mm)										
	Implant placement	**Mesial**	20	-0.07 ± 0.24	0	0	-1.00 to 0.00	20	-0.08 ± 0.15	0
		Distal		-0.05 ± 0.18	0	0	-0.73 to 0.00		-0.11 ± 0.18	0
		Mean		-0.06 ± 0.14	0	0	-0.50 to 0.00		-0.09 ± 0.12	0.05
	6 months	**Mesial**	20	-0.27 ± 0.31	0.15	0.28	-1.28 to 0.00	20	-0.33 ± 0.30	0.22
		Distal		-0.29 ± 0.42	0.21	0.5	-1.62 to 0.10		-0.40 ± 0.42	0.38
		Mean		-0.28 ± 0.28	0.22	0.4	-1.11 to -0.01		-0.39 ± 0.33	0.36
	1 year	**Mesial**	18	-0.41 ± 0.47	0.24	0.83	-1.28 to 0.23	20	-0.50 ± 0.75	0.24
		Distal		-0.51 ± 0.68	0.31	0.69	-2.26 to 0.12		-0.51 ± 0.58	0.26
		Mean		-0.46 ± 0.50	0.28	0.44	-1.73 to -0.09		-0.50 ± 0.63	0.3
	3 years	**Mesial**	15	-0.28 ± 0.50	0.16	0.93	-1.23 to 0.34	17	-0.42 ± 0.70	0.19
		Distal		-0.48 ± 0.68	0.27	0.84	-1.88 to 0.34		-0.59 ± 1.14	0.33
		Mean		-0.38 ± 0.55	0.26	0.52	-1.55 to 0.34		-0.50 ± 0.90	0.27
(b) Change of marginal bone level (mm)										
	Implant placement - 1 year	**Mesial**	18	-0.34 ± 0.47	-0.22	0.57	-1.28 to 0.23	20	-0.42 ± 0.77	-0.11
		Distal		-0.46 ± 0.68	-0.26	0.53	-2.26 to 0.12		-0.40 ± 0.60	-0.17
		Mean		-0.40 ± 0.53	-0.22	0.49	-1.73 to 0.14		-0.41 ± 0.66	-0.16
	Implant placement - 3 years	**Mesial**	15	-0.21 ± 0.62	0.16	0.95	-1.23 to 1.20	17	-0.33 ± 0.78	0.15
		Distal		-0.41 ± 0.65	0.26	0.43	-1.88 to 0.34		-0.48 ± 1.15	0.13
		Mean		-0.31 ± 0.59	0.21	0.59	-1.55 to 0.67		-0.40 ± 0.93	0.1
	1 year - 3 years	**Mesial**	15	0.17 ± 0.37	-0.08	0.6	-0.23 to 1.08	17	-0.01 ± 0.35	-0.04
		Distal		-0.41 ± 0.65	-0.01	0.54	-1.88 to 1.94		-0.08 ± 0.65	-0.06
		Mean		0.14 ± 0.59	-0.01	0.6	-1.05 to1.25		-0.05 ± 0.41	-0.04

Results of Mann-Whithney test.
Ti 4.1, titanium 4.1 mm diameter implants; Ti-Zr 3.3, titanium-zirconium 3.3 mm diameter implants; n, number; SD, standard deviation; IQR, interquartile range.

	Ti 4.1 (n = 15)				Ti-Zr 3.3 (n = 17)				
	Mean ± SD	Median	IQR	Range	Mean ± SD	Median	IQR	Range	p-value *
FMPS (%)	27.3 ± 14.5	22	20	12 to 65	19.6 ± 12.0	15	17	5 to 49	0.061
FMBS (%)	15.7 ± 11.6	12	16	0 to 36	6.9 ± 7.3	4	9	0 to 24	0.028 ?
PCR (%)	10.0 ± 16.4	0	9	0 to 50	7.7 ± 11.9	0	17	0 to 33	0.911
BoP (%)	20.0 ± 19.1	17	33	0 to 67	13.8 ± 17.9	0	25	0 to 50	0.298
PPD (mm)	2.9 ± 0.8	2.7	0.7	1.8 to 4.3	2.6 ± 0.8	3	1.3	1.2 to 3.7	0.732
KM (mm)	2.8 ± 1.1	3	2	0 to 4	3.2± 1.1	3	1.5	1 to 5	0.314

* Results of Mann-Whitney test. Ti 4.1, titanium 4.1 mm diameter implants; Ti-Zr 3.3, titanium-zirconium 3.3 mm diameter implants; n, number; SD, standard deviation; IQR, interquartile range; FMPS, full-mouth plaque score; FMBS, full-mouth bleeding score; PCR, plaque control record; BOP, bleeding on probing; PPD, probing pocket depth; KM, width of keratinized mucosa. ? p ? 0.05

		Ti 4.1					Ti-Zr 3.3					
		n	Mean ± SD	Median	IQR	Range	n	Mean ± SD	Median	IQR	Range	p-value *
(a) Change of the mesial papilla level	**6 months to 1 year**	18	0.8 ± 1.3	0.3	2	-1.0 to 3.0	19	0.5 ± 1.4	0	1.5	-2.5 to 3.5	0.558
	6 months to 3 years	15	0.5 ± 1.4	1	2	-2.0 to 3.0	16	0.3 ± 1.6	1.6	2.8	-2.5 to 3.5	0.572
	1 year to 3 years	15	-0.2 ± 1.4	0	1	-2.0 to 3.0	16	-0.3 ± 0.8	0	0.9	-2.0 to 1.0	0.892
(b) Change of the distal papilla level	**6 months to 1 year**	18	0.8 ± 1.0	0.8	1.3	-1.0 to 3.0	19	0.1 ± 1.5	0	2	-2.5 to 3.0	0.07
	6 months to 3 years	15	-0.1 ± 1.4	1	2	-3.0 to 2.0	16	-0.5 ± 1.7	0	1.4	-4.0 to 3.0	0.682
	1 year to 3 years	15	-0.8 ± 1.3	-0.5	2	-4.0 to 1.0	16	-0.4 ± 1.3	0	1	-4.0 to 2.0	0.401
(c) Change of the mid-facial mucosa level	**6 months to 1 year**	18	0.2 ± 0.6	0	0.6	-1.0 to 1.5	19	0.0 ± 0.8	0	1	-2.0 to 1.0	0.48
	6 months to 3 years	15	-0.3 ± 1.1	0.5	0	-3.0 to 1.5	16	-0.3 ± 0.9	-0.5	1.4	-2.0 to 1.0	0.281
	1 year to 3 years	15	-0.5 ± 0.8	0	1	-3.0 to 0.0	16	-0.2 ± 0.4	0	0.5	-1.0 to 0.5	0.572

Results of Mann-Whitney test for the inter-group analysis. Ti 4.1, titanium 4.1 mm diameter implants; Ti-Zr 3.3, titanium-zirconium 3.3 mm diameter implants; n, number; SD, standard deviation ; IQR, interquartile range.